Contents

Preface vii

COMPOUND SEMICONDUCTORS

Molecular layer epitaxy of GaAs
J. Nishizawa 1

Recent advances in atomic layer epitaxy devices
S.M. Bedair and N.A. El-Masry 7

Silicon doping with modulated beam epitaxy in the growth of GaAs(111)A
M.R. Fahy, K. Sato and B.A. Joyce 14

Atomic layer epitaxy of device quality AlGaAs and AlAs
N. Hayafuji, G.M. Eldallal, A. Dip, P.C. Colter, N.A. El-Masry and S.M. Bedair 18

Substrate misorientation dependence of thermal stability of Si atom in Si atomic layer doped GaAs on GaAs(111)A
M. Hirai, H. Ohnishi, K. Fujita and T. Watanabe 23

Investigation of a GaN surface structure for the mask of GaAs selective growth using MOMBE
S. Yoshida and M. Sasaki 28

Atomic layer epitaxy growth of doped zinc oxide thin films from organometals
V. Lujala, J. Skarp, M. Tammenmaa and T. Suntola 34

Selective MLE growth of GaAs and surface treatment for ideal static induction transistor (ISIT) application
Y. Oyama, P. Plotka and J. Nishizawa 41

Pulsed-jet epitaxy: application to device processes
Y. Sakuma, M. Ozeki, N. Ohtsuka, Y. Matsumiya, H. Shigematsu, O. Ueda, S. Muto, K. Nakajima and N. Yokoyama 46

Surface processes of selective growth by atomic layer epitaxy
H. Isshiki, Y. Aoyagi, T. Sugano, S. Iwai and T. Meguro 57

Epitaxial growth of a two-dimensional structure of GaP on a Si substrate by metalorganic chemical vapor deposition
T. Soga, T. Jimbo and M. Umeno 64

Migration and related buried epitaxy using digital epitaxial growth conditions
I. Takahashi, M. Nakaji and H. Kawanishi 70

Growth temperature dependence of optical properties of gas source MBE grown GaP/AlP short period superlattices
J.H. Kim, H. Asahi, K. Asami, K. Iwata, S.G. Kim and S. Gonda 76

Fabrication of smooth facets of InP by selective sidewall epitaxy using CBE
M. Gotoda, H. Sugimoto, S. Maruno, T. Isu, W. Susaki and M. Nunoshita 80

Selective epitaxial growth of GaInP by LP-MOCVD using ethyldimethylindium, trimethylindium, trimethylgallium and triethylgallium as group III sources
S.-H. Chan, S.M. Sze, C.-Y. Chang and W.-I. Lee 85

Ideal static induction transistor implemented with molecular layer epitaxy
P. Płotka, T. Kurabayashi, Y. Oyama and J. Nishizawa 91

Temperature synchronized molecular layer epitaxy
T. Kurabayashi and J. Nishizawa 97

Autocompensation in Si planar doped GaAs
T. Suzuki, H. Goto, N. Sawaki, H. Ito and K. Hara 103

Optical properties of atomic layer grown InAs/AlSb quantum well structures by gas source migration enhanced epitaxy
H. Asahi, S.G. Kim, M. Seta, K. Asami, H. Watanabe, T. Ogura and S. Gonda 109

Microscopic analysis of interface structure in InGaAs/InP MQW using Pendellösung oscillation around a satellite peak in high-resolution X-ray diffraction
M. Takemi, T. Kimura, K. Mori, K. Goto, Y. Mihashi and S. Takamiya 115

Growth of In_2S_3 thin films by atomic layer epitaxy
T. Asikainen, M. Ritala and M. Leskelä 122

Flow modulation epitaxy of $Ga_xIn_{1-x}As$/AlAs heterostructures on InP for resonant tunneling diodes
B.P. Keller, J.C. Yen, A.L. Holmes Jr., S.P. DenBaars and U.K. Mishra 126

AlAs layers with low carbon content grown by ALE using ethyldimethylamine alane as a new aluminum source
N. Kano, S. Hirose, K. Hara, J. Yoshino, H. Munekata and H. Kukimoto 132

Comparative study between MEE- and MBE-grown InSb-nanocrystals on Se-terminated GaAs(001)
Y. Watanabe, F. Maeda and M. Oshima 136

SURFACE STRUCTURES AND REACTION PROCESSES

Surface diffusion and adatom stoichiometry in GaAs MBE studied by microprobe-RHEED/SEM MBE
T. Nishinaga and X.Q. Shen 141

Role of a metalorganic As source in atomic layer epitaxy of GaAs and AlAs
I. Suemune 149

Self-limiting and step-propagating nature of GaAs atomic layer epitaxy revealed by atomic force microscopy
H. Yokoyama, M. Tanimoto, M. Shinohara and N. Inoue 158

Kinetics and mechanism of atomic layer epitaxy of GaAs using trimethylgallium
H. Ohno, S. Goto, Y. Nomura, Y. Morishita and Y. Katayama 164

Surface stoichiometry and the role of adsorbates during GaAs atomic layer epitaxy
J.R. Creighton 171

Activation of the Ga–CH_3 bond using atomic hydrogen – a possible route to III–V semiconductor films with low carbon levels
J.T. Yates, Jr., A. Hübner, S.R. Lucas, W.D. Partlow, J. Schaefer and W.J. Choyke 180

Control of the etching reaction of digital etching using tunable UV laser irradiation
T. Meguro, M. Ishii, T. Sugano, K. Gamo and Y. Aoyagi 193

Theoretical studies on the chloride ALE process
Y. Mochizuki, T. Takada and A. Usui 200

A Monte Carlo simulation study for adatom migration and resultant atomic arrangements in $Al_xGa_{1-x}As$ on a GaAs(001) surface
T. Ito, K. Shiraishi and T. Ohno 208

Configurational atomic ordering caused by stochastic adsorption processes in MBE-grown alloy semiconductors
H. Nakayama, M. Tochigi, H. Maeda and T. Nishino 214

In-situ monitoring of 1st-order phase transition on InAs(001) surfaces by scanning electron surface microscopy
H. Yamaguchi, Y. Homma and Y. Horikoshi 223

Optical in-situ analysis of GaAs/AlAs/GaAs and GaAs/(Al)GaAs/GaAs atomic layer growth using $GaCl_3$, $AlCl_3$ and AsH_3
M. Akamatsu, S. Narahara, T. Kobayashi and F. Hasegawa 228

Atomic layer epitaxy of AlAs: growth mechanism
M. Ozeki and N. Ohtsuka 233

A solution to the surface arsenic stoichiometric problem at the GaAs(001) growth surface in atomic layer expitaxy
Y. Sakuma, S. Muto, K. Nakajima and N. Yokoyama 239

X-ray photoelectron spectroscopic and atomic force microscopic study of GaAs etching with a HCl solution
Z. Song, S. Shogen, M. Kawasaki and I. Suemune 250

Substitution of surface-adsorbed As atoms to P atoms in atomic layer epitaxy
H. Ikeda, Y. Miura, N. Takahashi, A. Koukitu and H. Seki 257

In-situ observation of Ga adsorption during TMGa exposure on GaAs(001) surfaces with various As coverages
S. Otake, A. Sakamoto, M. Yamamoto and I. Iwasa 263

Pulsed trimethylgallium scattering from As-stabilized and Ga-stabilized surfaces
M. Sasaki and S. Yoshida 269

Surface reactions of Ga and As on Sb-terminated GaAs(001)
F. Maeda, Y. Watanabe and M. Oshima 276

Carbon incorporation mechanism in atomic layer epitaxy of GaAs and AlGaAs
N. Kobayashi and T. Makimoto 284

Real time observation of surface dielectric responses of GaAs(001) using surface photo-absorption
K. Uwai and N. Kobayashi 290

Atomic layer epitaxy of ZnSe using reflectance difference spectroscopy
H. Akinaga and K. Tanaka 298

CO adsorption on clean and atomic-layer-Cu-covered ZnO($10\bar{1}0$) surfaces
Q. Ge and P.J. Møller 305

Chlorine adsorption on electron beam irradiated GaAs photo-oxides: mechanism of in situ EB lithography
Y. Ide and M. Yamada 310

Surface reaction mechanism in MOMBE-ALE of ZnSe and CdSe as determined by a new in-situ optical probing method
A. Yoshikawa, M. Kobayashi and S. Tokita 316

SILICON AND GERMANIUM

Hydrogen atom assisted ALE of silicon
S. Imai and M. Matsumura 322

Photoelectron intensity oscillation as a probe to monitor Si layer-by-layer growth
Y. Enta, N. Miyamoto, Y. Takakuwa and H. Kato 327

Sub-atomic-layer epitaxy of Si using Si_2H_6
Y. Suda, M. Ishida, M. Yamashita and H. Ikeda 332

Suppression of HBO_2 and Sb adsorption on thin-oxide-covered, H-terminated, or Sb-terminated Si(100) surfaces
E. Murakami, H. Kujirai and S. Kimura 338

Si ALE using chlorine/hydrogen exchange. Fundamentals and films
D.D. Koleske and S.M. Gates 344

Self-limiting adsorption of thermally cracked $SiCl_2H_2$ on Si surfaces
C. Sasaoka and A. Usui 348

Atomic-layer epitaxy control of Ge and Si in flash-heating CVD using GeH_4 and SiH_4 gases
M. Sakuraba, J. Murota, T. Watanabe, Y. Sawada and S. Ono 354

Adaptive temperature program ALE of $Si_{1-x}Ge_x$/Si heterostructures from Si_2H_6/Ge_2H_6
S. Asami, N.M. Russell, A. Mahajan, P.A. Steiner IV, D.J. Bonser, J. Fretwell, S. Bannerjee, A. Tasch, J.M. White and J.G. Ekerdt 359

Scanning tunneling microscopy study of solid-phase epitaxy processes of amorphous silicon layers on silicon substrates
K. Uesugi, T. Komura, M. Yoshimura and T. Yao 367

Scanning tunneling microscopy observations of Ge solid-phase epitaxy on Si(111)
H. Hibino and T. Ogino 374

Atomic layer epitaxy of germanium
S. Sugahara, T. Kitamura, S. Imai and M. Matsumura 380

Auger electron diffraction study of the initial stage of Ge heteroepitaxy on Si(001)
M. Sasaki, T. Abukawa, H.W. Yeom, M. Yamada, S. Suzuki, S. Sato and S. Kono 387

Temperature effects on synchrotron-radiation-excited Si atomic layer epitaxy using disilane
H. Akazawa 394

Boron δ-doping in Si using atmospheric pressure CVD
Y. Kiyota, T. Nakamura and T. Inada 400

Mechanisms of SiC growth by alternate supply of SiH_2Cl_2 and C_2H_2
H. Nagasawa and Y. Yamaguchi 405

Isothermal H_2 desorption kinetics from Si(100)2×1: dependence on disilane and atomic hydrogen precursors
L.A. Okada, M.L. Wise and S.M. George 410

Low temperature adsorption of hydrogen on Si(111) and (100) surfaces studied by elastic recoil detection analysis
M. Watamori, M. Naitoh, H. Morioka, Y. Maeda and K. Oura 417

Substrate orientation dependence of self-limited atomic-layer etching of Si with chlorine adsorption and low-energy Ar^+ irradiation
K. Suzue, T. Matsuura, J. Murota, Y. Sawada and T. Ohmi 422

Atomic-scale modification of the $AlCl_3$-adsorbed Si(111)-7×7 surface
T. Takiguchi, K. Uesugi, M. Yoshimura and T. Yao 428

Chemical reactivity of the Si(111)$(\sqrt{3} \times \sqrt{3})$R30°-B surface: an electron-energy-loss spectroscopy study
Y. Taguchi, M. Daté, N. Takagi, T. Aruga and M. Nishijima 434

Adsorption and desorption of H_2O on potassium precovered Si(100)2×1 surface
S. Hongo, S. Taniguchi, K. Ojima, T. Urano and T. Kanaji 437

Scanning tunneling microscope observations of Si(111)3×1-Ag and 6×1-Ag structures
H. Ohnishi, Y. Yamamoto, I. Katayama, Y. Ohba and K. Oura 444

Temperature-programmed-desorption study of the process of atomic deuterium adsorption onto Si(100)2×1
M. Suemitsu, H. Nakazawa and N. Miyamoto 449

OXIDES AND METALS

Atomic layer epitaxy in the growth of complex thin film structures for electroluminescent applications
L. Niinistö and M. Leskelä 454

Atomic layer controlled deposition of SiO_2 and Al_2O_3 using ABAB... binary reaction sequence chemistry
S.M. George, O. Sneh, A.C. Dillon, M.L. Wise, A.W. Ott, L.A. Okada and J.D. Way 460

$NbCl_5$ as a precursor in atomic layer epitaxy
K.-E. Elers, M. Ritala, M. Leskelä and E. Rauhala 468

Atomic force microscopic study of directional $SrSO_4$(001) surface and its etching property
A. Seo and H. Shindo 475

In situ ellipsometric diagnostics for controlled growth of metal oxides with surface chemical reactions
H. Kumagai and K. Toyoda 481

Layer controlled growth of oxide superconductors
M. Kawai, Z.-Y. Liu, T. Hanada, M. Katayama, M. Aono and C.F. McConville 487

Preparation of ultra-flat YBCO thin films by MOCVD layer-by-layer deposition
M. Matsubara and I. Hirabayashi 494

Fabrication of CuO_2-plane-based high-temperature superconducting thin films by atomic layer controlled molecular beam epitaxy
I. Yoshida, H. Furukawa, T. Hirosawa and M. Nakao 501

Morphology of epitaxial SrF_2 films on atomically modified InP(100)
S. Heun, M. Sugiyama, S. Maeyama, Y. Watanabe and M. Oshima 507

Steric and electronic interactions between source gas and substrate surface during the Al-CVD/Al selective epitaxy process as investigated by quantum chemical calculations
R. Vetrivel, R. Yamauchi, H. Yamano, M. Kubo, A. Miyamoto and T. Ohta 516

Surface modification of CaF_2 in atomic layer scale by electron beam exposure
S.M. Hwang, A. Izumi, K. Tsutsui and S. Furukawa 523

Structural study of $SrTiO_3$(100) surfaces by low energy ion scattering
Y. Tanaka, H. Morishita, M. Watamori, K. Oura and I. Katayama 528

Surface structure dependence of O_2–W adsorption system
M. Sato 532

Observation of the interface of Ba/Si(100) by MDS and TDS
S. Hongo, K. Ojima, S. Taniguchi, T. Urano and T. Kanaji 537

Theoretical estimation of ordered metal species in zeolite pores
H. Himei, E. Maruya, M. Kubo, R. Vetrivel and A. Miyamoto 543

Surface coverage of ALE precursors on oxides
S. Haukka, E.-L. Lakomaa and T. Suntola 548

The effect of growth parameters on the deposition of CaS thin films by atomic layer epitaxy
J. Rautanen, M. Leskelä, L. Niinistö, E. Nykänen, P. Soininen and M. Utriainen 553

Formation processes of ultrafine metal particles on MgO(100) as investigated by molecular dynamics and computer graphics
M. Kubo, R. Yamauchi, R. Vetrivel and A. Miyamoto 559

Oxidation of TiN thin films in an ion-beam-assisted deposition process
H. Kubota, M. Nagata, R. Miyagawa and M.A. Nicolet 565

Influence of atomic Cu-layer epitaxy on CO_2 and CO photoinduced desorption from ZnO(0001)
P.J. Møller, S.A. Komolov and E.F. Lazneva 569

Growth of extra-thin ordered aluminum films on Si(111) surface
E.A. Khramtsova, A.V. Zotov, A.A. Saranin, S.V. Ryzhkov, A.B. Chub and V.G. Lifshits 576

Electrical properties of Si–Al_2O_3 structures grown by ML-ALE
V.E. Drozd, A.P. Baraban and I.O. Nikiforova 583

Synthesis of oxide superalloys by ML-ALE method
V.E. Drozd, A.A. Tulub, V.B. Aleskovski and D.V. Korol'kov 587

Synthesis of conducting oxides by ML-ALE
V.E. Drozd and V.B. Aleskovski 591

Author index 595

Subject index 602